AP issues in the IR upgrade

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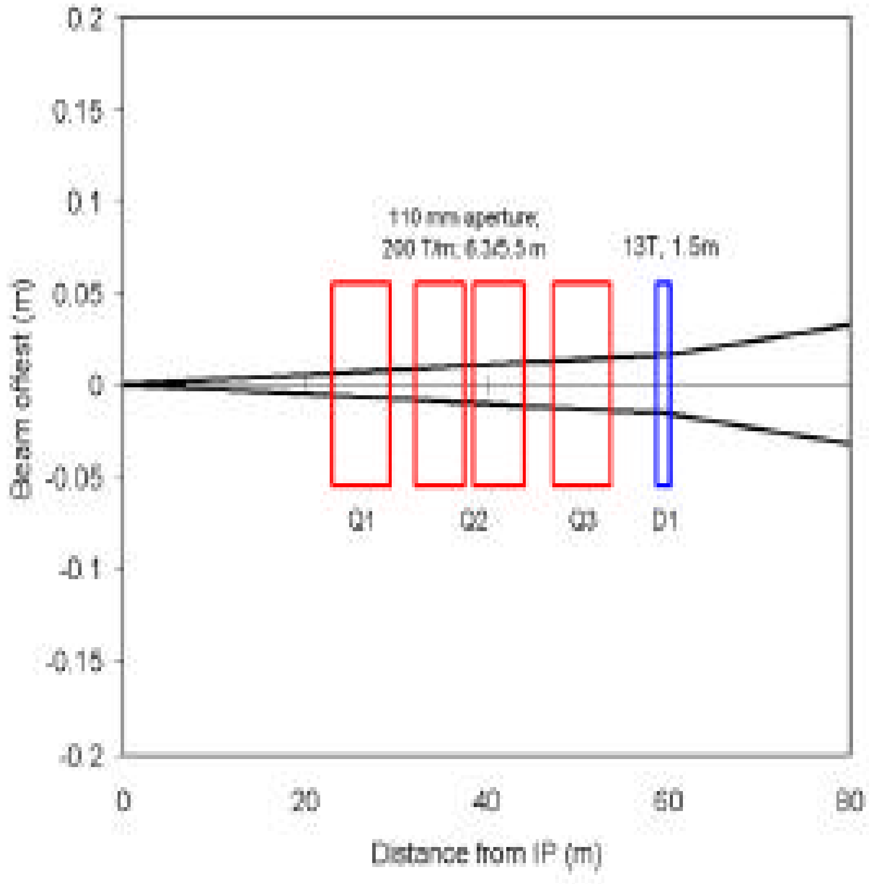
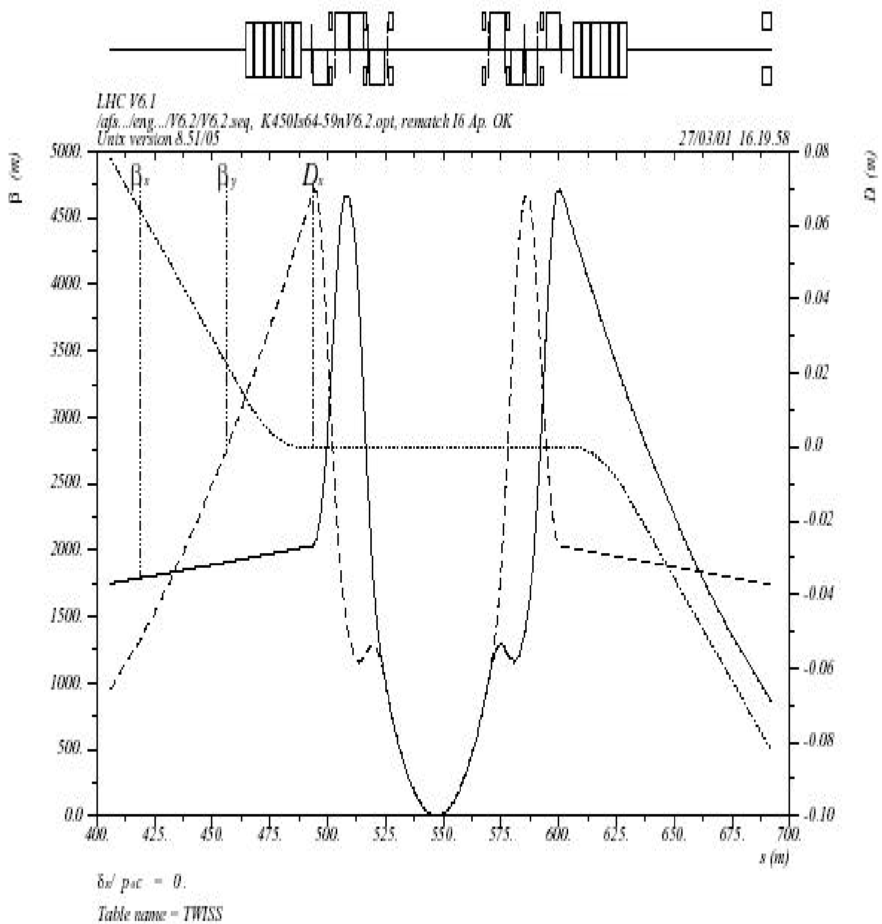
FNAL

Baseline Layout



- Quadrupoles first followed by separation dipoles
- Beams go off-axis in the quadrupoles
- Correction algorithm acts on both beams
- 16 long-range interactions on either side of IP

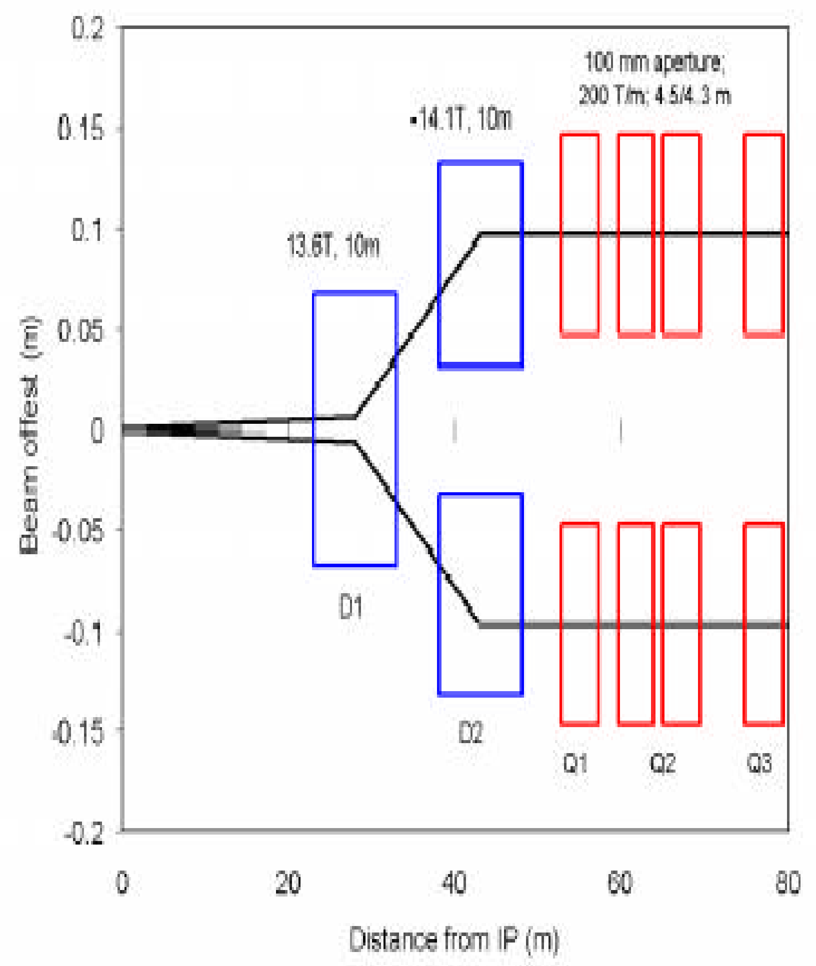
Baseline Optics and Upgrade



- ß* = 50cm, ß$_{max}$ = 5 km
- Hor. crossing angle at one high luminosity IP, vertical at the other
- Zero dispersion within the straight.

- Upgrade: larger apertures, same gradients
- ß* = 16cm, ß$_{max}$ = 15 km

Separation Dipoles First



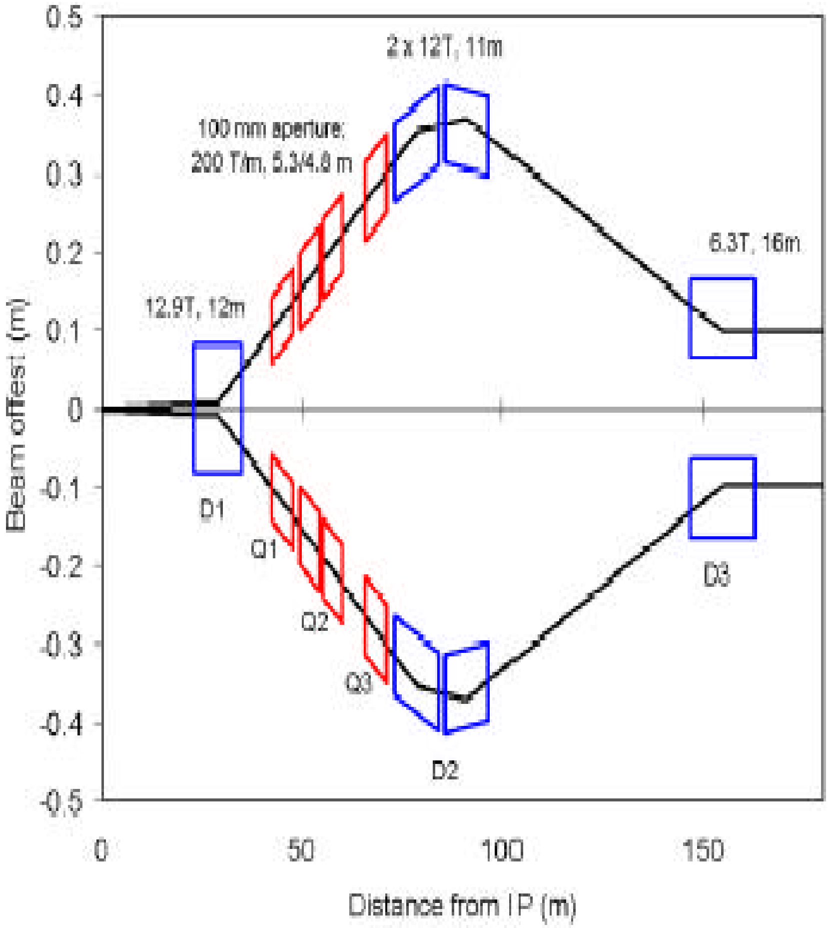
Pros

- Reduces long-range interactions 3 fold
- Independent nonlinear correction for each beam

Cons

- Larger ß* for the same $ß_{max}$
- Higher energy deposition in D1 from charged particles

Quads between D1 and D2



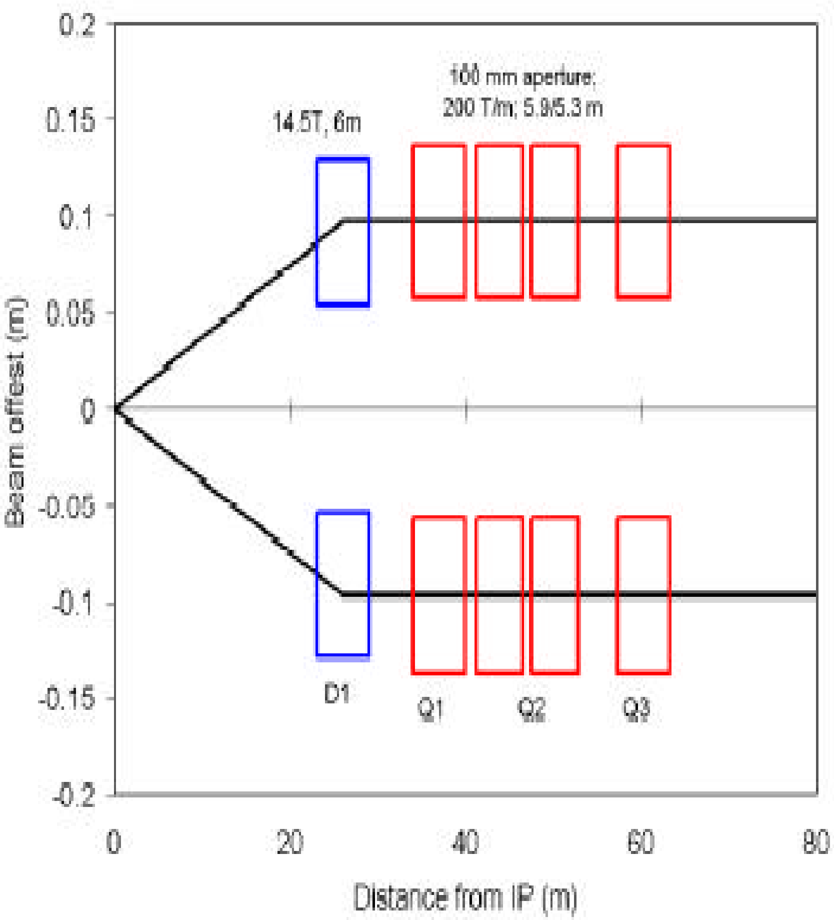
Pros

- Early beam separation reduces number of parasitics.
- Quads closer to the IP allows lower $ß^*$ for the same $ß_{max}$ than Option 2.

Cons

- Dual bore quads with non-parallel axes. Magnet and AP issues.
- Large energy deposition in D1.

Large X-angle: dipole first



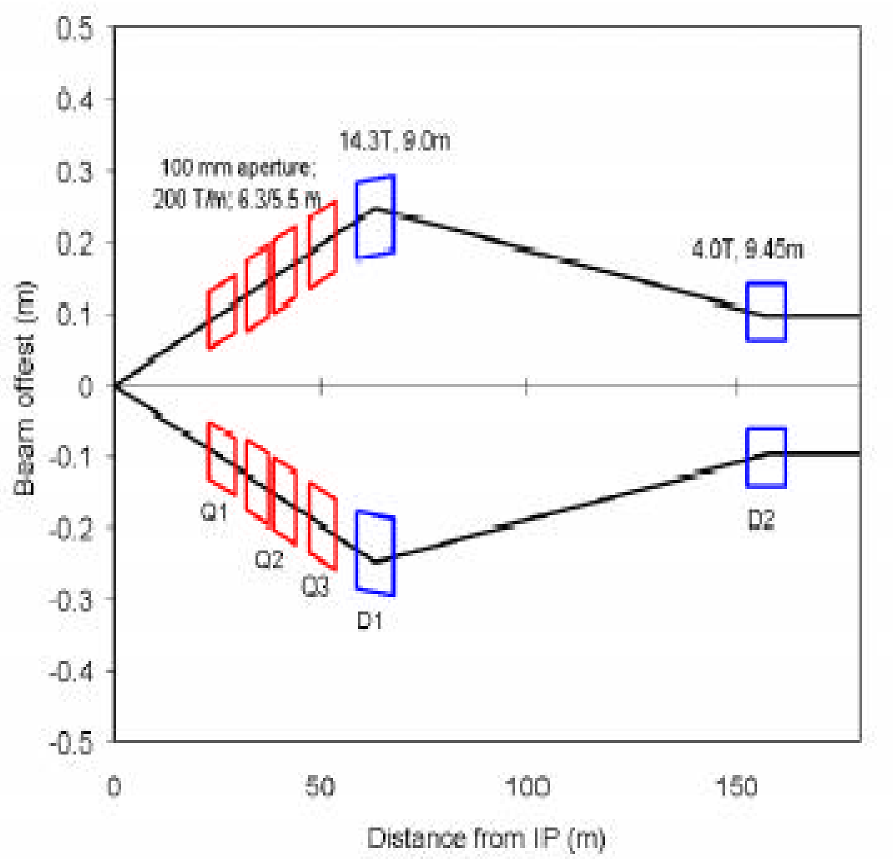
Pros

- Simplest layout for large crossing angle (±3.7 mrad)
- Allows lower $ß^*$ for the same $ß_{max}$ than Options 2 and 3.

Cons

- D1 suffers greater radiation damage than in previous options from neutral particles.

Large X-angle: quads first



Pros

- Allows the lowest ß* for the same $ß_{max}$.

Cons

- Dual bore quads with non-parallel axes. Magnet and AP issues.
- Large energy deposition in D1.

IR Parameters

	Base-line	Fig. 1	Fig. 2	Fig. 3	Fig. 4	Fig. 5
IP to Q1 (m)	23	23	52.8	42.5	34	23
D_{quad} (mm)	70	110	100	100	100	100
β^*_{min} (cm)	50	16	26	19	15	10
β_{max} (km)	5	15	23	23	23	23
B_{D1} (T)	2.75	15.3	15	14.6	14.5	14.3
L_{D1} (m)	9.45	1.5	10	12	6	9
D_{D1} (mm)	80	110	135	165	75	105

AP issues related to the IR

- Gradients and apertures of magnets
- Orbit and coupling correction within the IR
- Nonlinear correction with small and large crossing angles.
- Linear and nonlinear chromaticity correction (for larger $ß_{max}$)
- Dynamic aperture (single beam) for different layouts
- Sensitivity to gradient and alignment errors
- Constraints on IR layout from injection optics
- Backgrounds in the IRs and Energy deposition

  e.g synchrotron radiation with large crossing angles
- Beam-beam effects

  long-range perhaps not an issue with early separation
- Impact of super-bunches – yes!

Triplet aperture requirements: baseline scheme

rough estimate of triplet quadrupole aperture $D_{\rm trip}$ for $\ell^* = 23\,\rm m$:

- $9\,\sigma$ beam envelope
- $7.5\,\sigma$ beam separation
- 20% β-beating
- 4 mm spurious dispersion
- 3 mm peak orbit excursion
- 1.6 mm mechanical tolerances
- beam screen and cold bore

Any requirements from detector backgrounds?

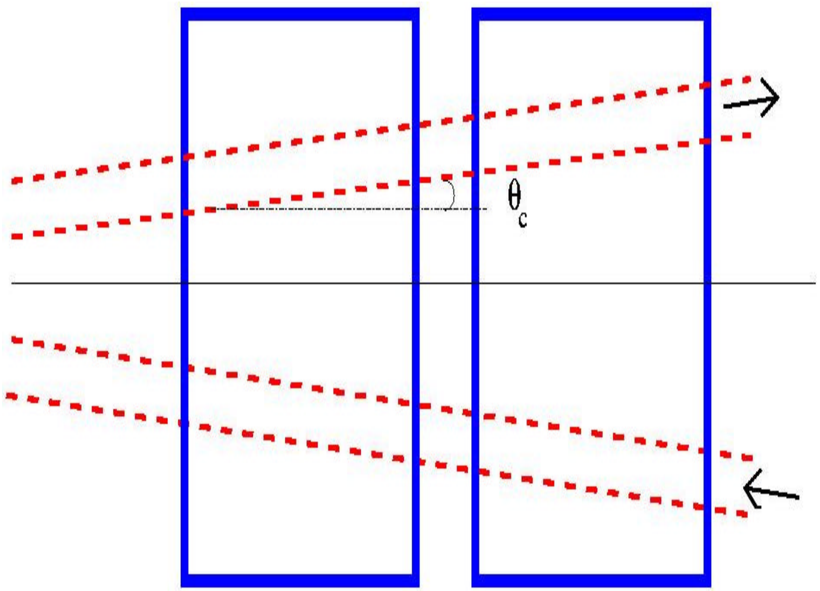
$$D_{\rm trip} > 1.1 \times (7.5 + 2 \times 9) \cdot \sigma + 2 \times 8.6\,\rm mm$$

$\beta^* = 0.5\,\rm m \rightarrow \sigma_{\rm max} \simeq 1.5\,\rm mm \Longrightarrow D_{\rm trip} > 60\,\rm mm \rightarrow$ <u>70 mm ID coil</u>

$\beta^* = 0.25\,\rm m \rightarrow \sigma_{\rm max} \simeq 2.2\,\rm mm \Longrightarrow D_{\rm trip} > 80\,\rm mm \rightarrow$ <u>90 mm ID coil</u>

Non-parallel axes

Dual aperture quads



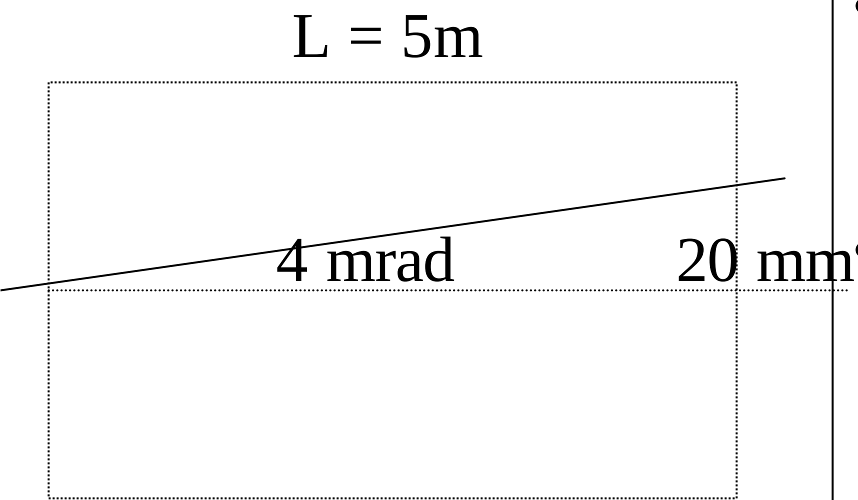
- Novel engineering to match magnet axes with beam axes.
- Range of crossing angles is constrained. If ?$_{c,nom}$ = 4mrad

  3 mrad < ?$_c$ < 5 mrad

  if r_{pipe} = 50mm, and Q3 is 50m from the IP.
- Physical aperture is sensitive to **longitudinal** and transverse alignments.
- Each quadrupole is different

  => reduces sorting possibilities.

Large crossing angles @ the beam-beam limit



Large feed-downs if beam axes not matched to magnet axes. If average offset =10mm and b_{10} = 0.1 => feed-down multipoles from b_{10} alone are,

- Feasible if beam current is not limited by other effects, e.g. electron cloud, instabilities.
- At a half crossing angle = 4 mrad

beam separation in drift space (6 ints.)

Baseline (ß*=0.5m)	Option 4 (ß*=0.15m)
d = 9.5s	d = 138s

=> Long-range not an issue

=> same crossing plane at both IPs

$b_9 = 0.6$, $b_8 = 1.6$, $b_7 = 2.4$, $b_6 = 2.5$, $b_5 = 1.8$, $b_4 = 0.9$, $b_3 = 0.3$, $b_2 = 0.06$

Correction for baseline optics

Corrector Strengths

The corrector strengths are found by minimizing the kicks on the particles (Wei et al., PAC99). Doing that in both planes requires that the following expressions are satisfied.

$$\int_L ds B_0 w_z \begin{pmatrix} b_n \\ a_n \end{pmatrix} + (-1)^n \int_R ds B_0 w_z \begin{pmatrix} b_n \\ a_n \end{pmatrix} = 0, \qquad z = x, y \tag{1}$$

Explicitly these equations for the corrector strengths $b_n^{(CL)}, b_n^{(CR)}$ can be written as

$$(B_0 L)^{CL} \langle \beta_x^{p_x} \beta_y^{p_y} \rangle_{CL} b_n^{(CL)} + (-1)^n (B_0 L)^{CR} \langle \beta_x^{p_x} \beta_y^{p_y} \rangle_{CR} b_n^{(CR)} = -\sum I_x(\text{quads}) \tag{2}$$

$$(B_0 L)^{CL} \langle \beta_x^{q_x} \beta_y^{q_y} \rangle_{CL} b_n^{(CL)} + (-1)^n (B_0 L)^{CR} \langle \beta_x^{q_x} \beta_y^{q_y} \rangle_{CR} b_n^{(CR)} = -\sum I_y(\text{quads}) \tag{3}$$

where the same powers of the beta functions occur on both sides, e.g

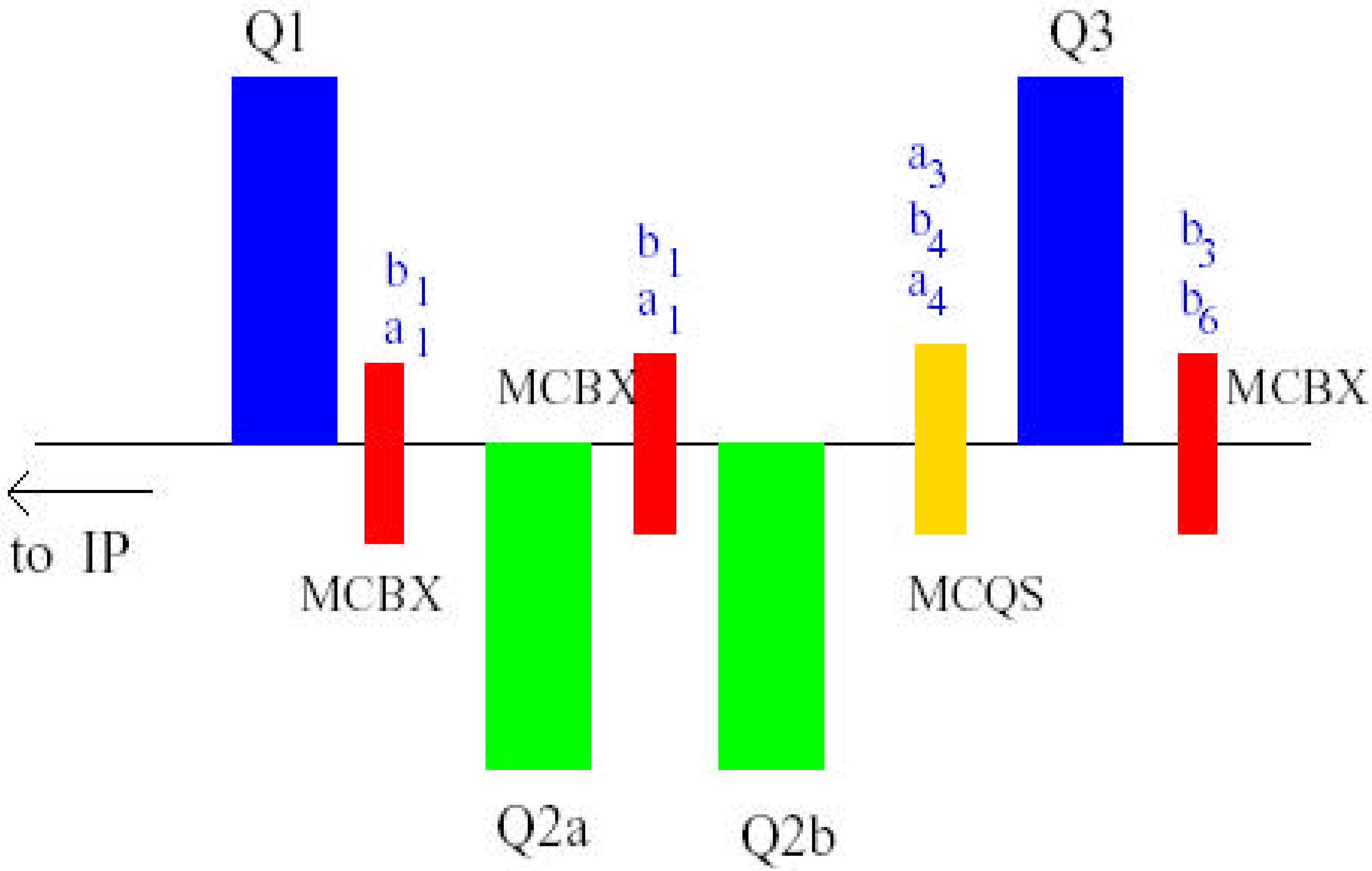
$$I_x(Q) = B' R_{ref} \int ds\, \beta_x^{p_x} \beta_y^{p_y} b_n \tag{4}$$

Similar equations for the a_n's.

Lowering β^* from 0.5 m to 0.25 m doubles the beta functions everywhere in the triplets and their vicnity, if the gradients are left unchanged. *If all the beta functions are scaled by the same factor, then the corrector strengths are unchanged.*

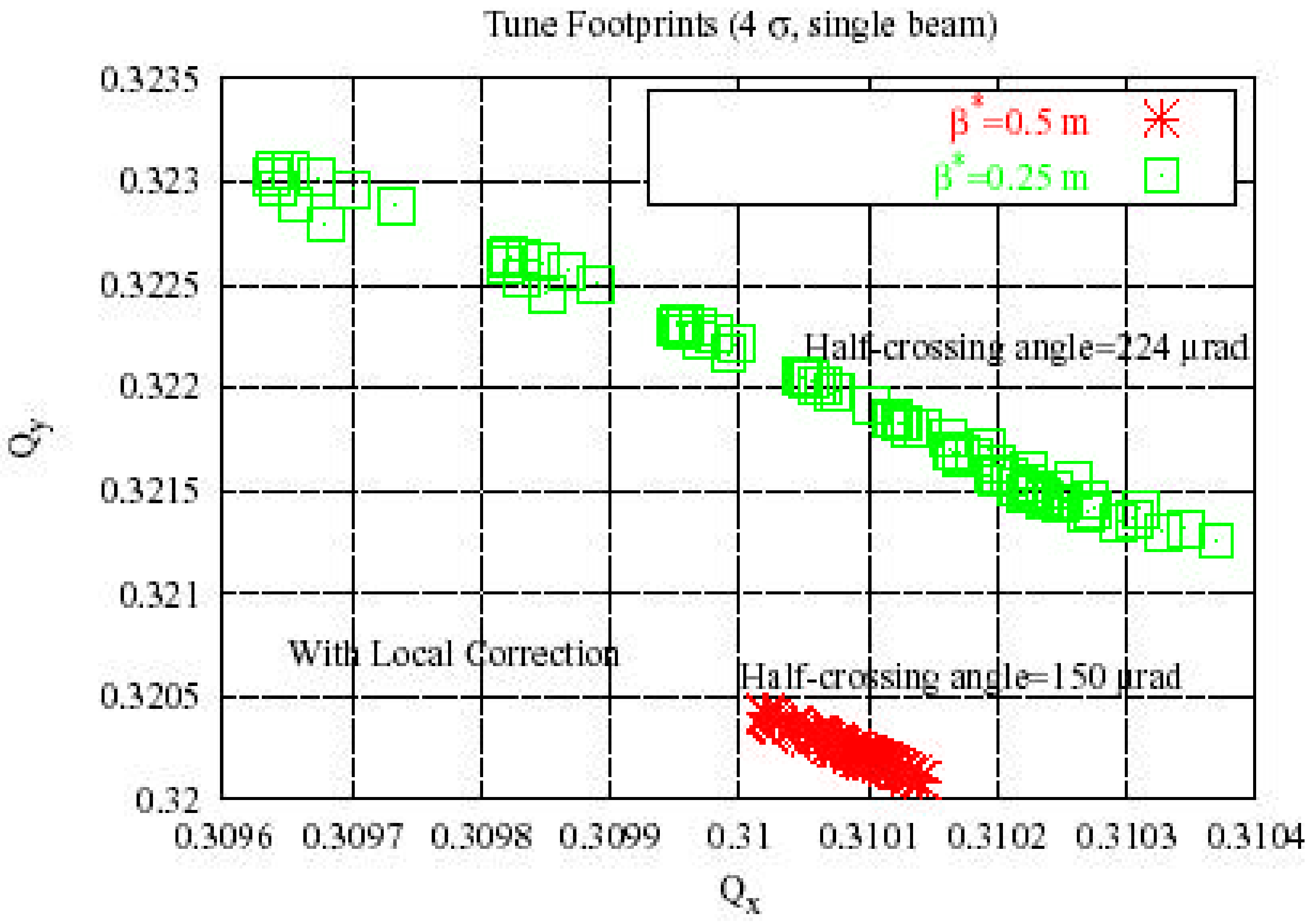
	Even b_n	Odd b_n	Even a_n	Odd a_n
w_x	$\beta_x^{n/2}$	$\beta_x^{n/2}$	$\beta_x^{(n-1)/2}\beta_y^{1/2}$	$\beta_x^{(n-1)/2}\beta_y^{1/2}$
w_y	$\beta_y^{n/2}$	$\beta_x^{1/2}\ \beta_y^{(n-1)/2}$	$\beta_x^{1/2}\ \beta_y^{(n-1)/2}$	$\beta_y^{n/2}$

Corrector Layout for baseline optics



Layout of local correctors

Nonlinear correction: baseline



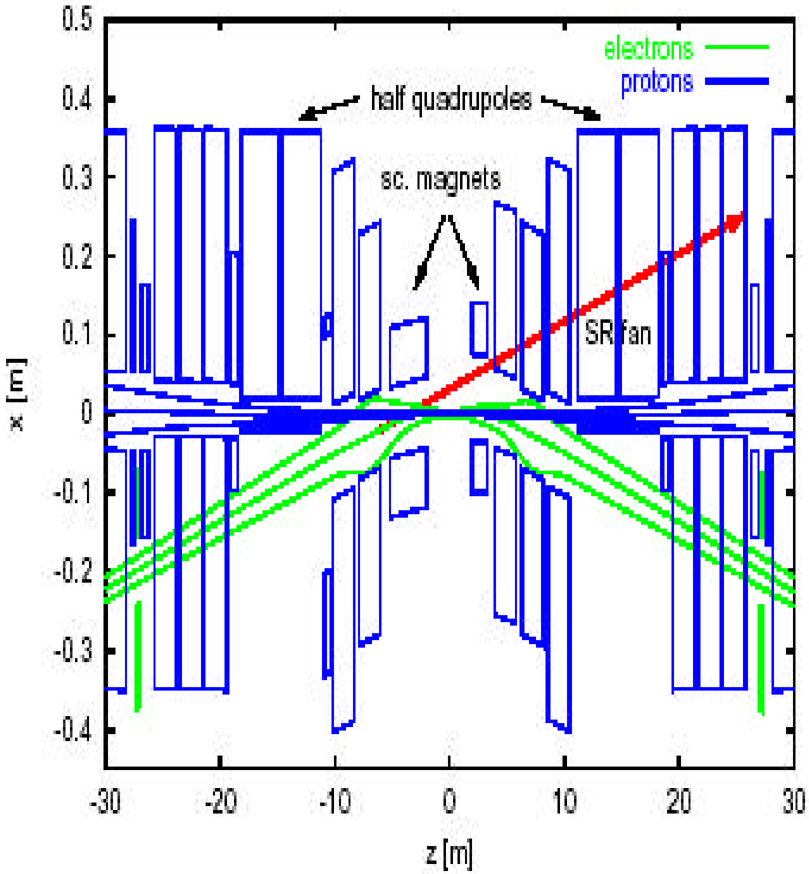
parameter	symbol	units	nominal	ultimate	Piwinski
number of bunches	n_{b}		2808	2808	2808
bunch spacing	Δt_{sep}	ns	25	25	25
protons per bunch	N_{b}	10^{11}	1.1	1.7	2.6
aver. beam current	I_{av}	A	0.56	0.86	1.32
norm. tr. emittance	ε_{n}	μm	3.75	3.75	3.75
long. emittance	ε_{L}	eV s	2.5	2.5	3.1
peak RF voltage	V_{RF}	MV	16	16	3
RF frequency	f_{RF}	MHz	400	400	200
r.m.s. bunch length	σ_z	cm	7.7	7.7	15.4
r.m.s. energy spread	σ_{E}	10^{-4}	1.1	1.1	0.70
IBS growth time	$\tau_{x,\mathrm{IBS}}$	h	108	70	78
beta at IP1-IP5	β^*	m	0.5	0.5	0.5
full crossing angle	θ_{c}	μrad	300	300	330
Piwinski parameter	$\theta_{\mathrm{c}}\sigma_z/\sigma^*$		1.46	1.46	3.2
lumi at IP1-IP5	L	$10^{34}/\mathrm{cm}^2\,\mathrm{s}$	1.0	2.3	3.6

Early work of the Task Force

A random list of the top 10 key questions for the task force included:

1. minimum acceptable number of future LHC experiments?
2. maximum number of events per collision the detectors can swallow?
3. minimum acceptable distance from the last magnet to the IP?
4. maximum gradient and aperture of future LHC quadrupoles?
5. maximum crossing angle and minimum acceptable beam separation at the parasitic collision points?
6. maximum beam intensity on the beam dump at 8 and 14 TeV?
7. maximum field and energy swing of future LHC dipoles?
8. magnet quench limit for higher LHC beam energy?
9. maximum energy of the last LHC injector?
10. highest brilliance and intensity the injectors can deliver?

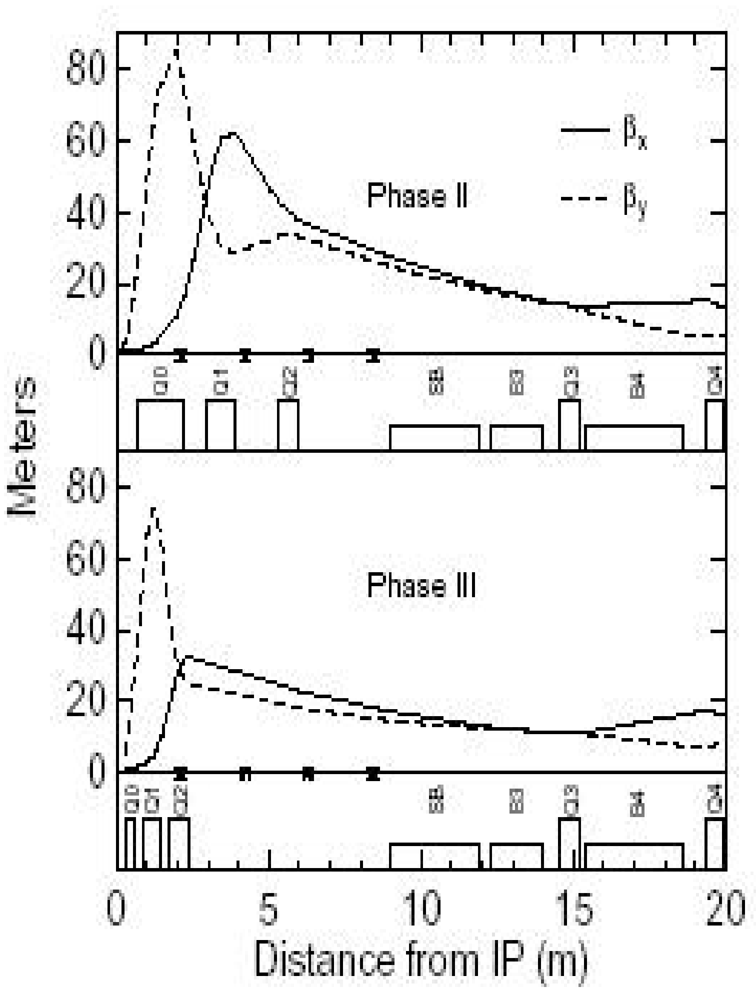
HERA Luminosity Upgrade



IR Layout after upgrade

- Path to higher luminosity
  - e quads moved closer to IP from 5.8m to 2m
  - p quads moved from 28m to 11m
  - earlier separation with SC dipoles partially in detector
  - stronger focusing in e-ring
- Specific Luminosity close to design
- Detector backgrounds (mainly synchrotron radiation) a major problem

CESR IR Upgrade



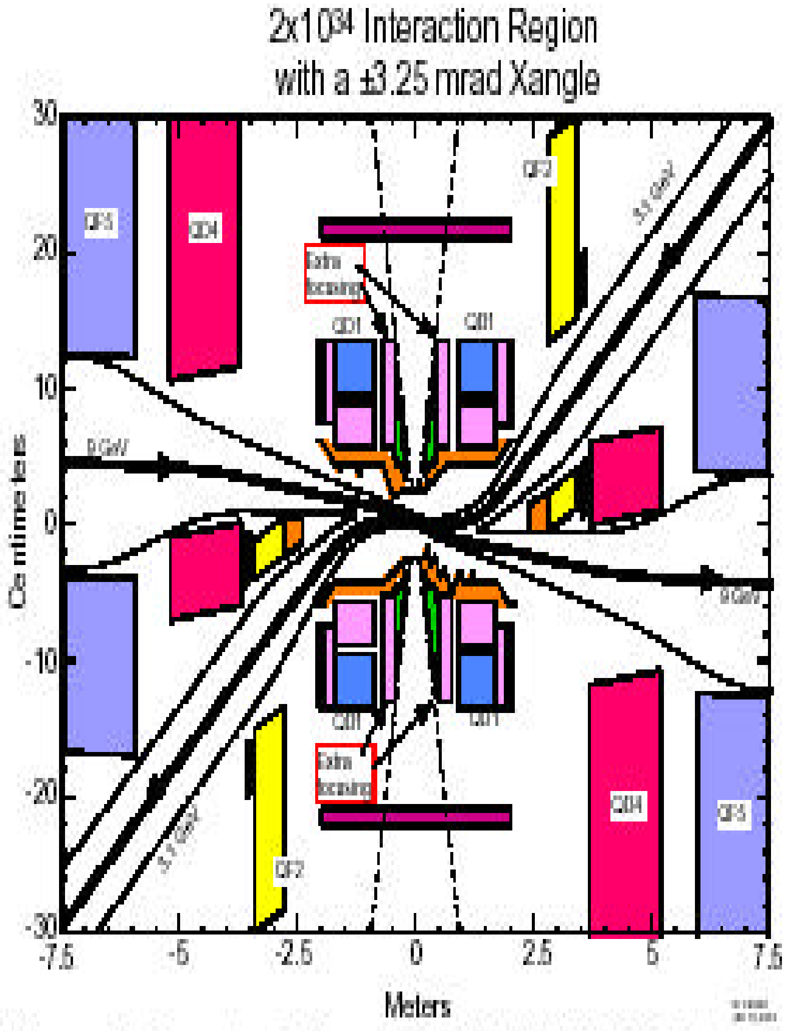
Henderson CBN 99-28

- Implemented in 2001
- Phase III insertion region within ±2.55 m of IP.

  First quad (permanent magnet) at 0.34m from IP
- ß$_y^*$ reduced from 18mm to (13 – 7) mm.
- Parasitics every 2.1m

  Betas at parasitics in IR same as in the arcs.
- SC rf allowed bunch length reduction from 19mm to 13mm

PEP-II IR Upgrade



Sullivan PAC03

- Planned for 2005
- 1st focusing quad will be moved closer to IP effectively by 0.2m to lower $ß_y^*$ to 5mm from 11-13mm.
- Requires shorter bunch lengths
- Introduce a 3.25mrad crossing angle – earlier separation
- Lower long-range tune shifts may allow more bunches (1 in each bucket).